Nov. 20, 12013

What Has Gone On Here?

Is this what is called soil?

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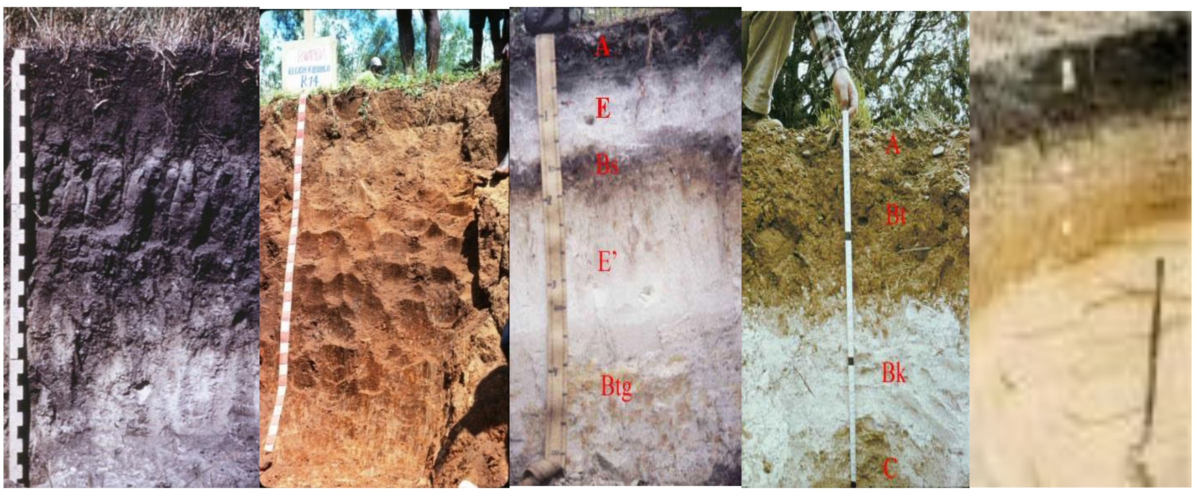


This looks more like a bowl of mixed fruit.

You say there is more than one kind of soil? How many?

There are at least 23,000 kinds of soil in the United States and an unknown number in the world.

Its Soils not Soil

Fifty years of playing in the dirt remembered by Stan Buol.

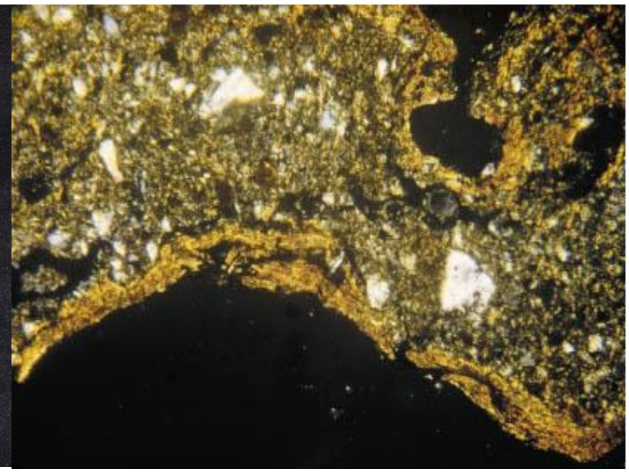
Starting to Find Out Why There Were So Many Soils

While mapping soils in southeastern Wisconsin I had the unique opportunity to spend about six weeks following a trench from near Fond du Lac to Milwaukee. There were a lot of things seen in a continuous trench that had never been imprinted on my mind from textbooks and lectures I had had during my undergraduate studies in Soil Science.



There were peat soils at the base of hills (left photo), some hills had almost no soil over limestone (center photo), and most areas had about 20 inches of gravel-free silt loam textured loess over glacial till (right photo). In some places the ‘stuff’ under the loess was stratified sand and gravel, outwash plains and in some places stratified clay called lacustrine beds. All of these features could be related to concepts of what went on when the area was freeing itself from a covering of glacial ice during the Wisconsin stage of glaciation about 10,000 years ago. The relationship of soils to geology seemed simple and therefore there was, in my mind no need to study geology if you wanted to understand soil.

However, the fascination of so many kinds of soil and their spatial relationships intrigued me and I proceeded to abandon my intensive undergraduate background in soil physics and proceed in graduate studies of soil genesis but concentrate on the climatic aspects by minoring in meteorology, geology was simple and I knew all I needed to know from field experience. Directed by Francis Hole I set about investigations of how organic matter was incorporated into the subsoil and focused on the presence of coatings that appeared present in the B horizons of almost all of the soils in Wisconsin. These coating which in 1959 we called ‘clay skins’ were to be called clay films when Soil Taxonomy defined the argillic horizon in the 7th Approximation.



Clay films (skins) were easily visible as dark reddish coatings on ped surfaces and along root channels in the lighter colored B horizons of Alfisols (Gray-Brown Podzolic) soils formed in loess and other glacial deposits in Wisconsin (left photo above). When thin sections were prepared from these peds and viewed with polarized light in a petrographic microscope they appeared as yellowish, highly birefringent coatings (right photo above). When discussing my work with Jim Thorp he enquired as to why clay films were not present in the B horizons of several other soils he had observed in other parts of the world. I could not come up with an answer.

I began to wonder if perhaps there were things going on in the genesis of soils that I was not aware of while studying soils in Wisconsin.

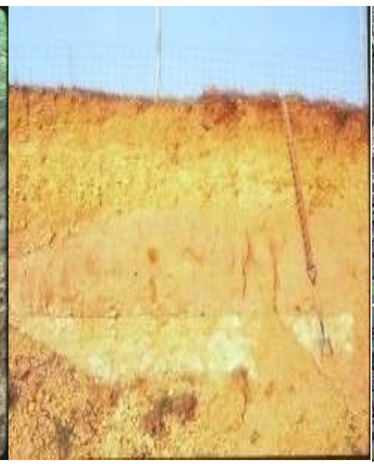
Now in Arizona, certainly a different climate from Wisconsin so I expected the soils to be different but several other things not directly related to climate differed from Wisconsin. I tried to find a site where I could demonstrate to my class a drainage catena related to topography and depth to water table, an every day activity encounter while mapping soils in Wisconsin only to find that the water table was usually several feet below the surface and never encroached on the soil profile. How could I demonstrate low chroma mottles and the process of gleization?

Most disturbing was finding a stratified layer of well-rounded stream gravel, clearly resembling outwash glacial deposits at a depth of about 3 feet under a soil on the highest elevation in the surrounding topography while conducting a field trip for my graduate class in Northern Arizona. No glacial activity had ever been reported in that area so that was not a plausible explanation. I needed help. I turned to professors in the Geology department where it was explained that the site was on the edge of the Colorado plateau and before the uplift of that plateau, some 70 million years ago streams flowed over the area bringing the mile thick sediments that were now seen in the Grand Canyon. The area was later covered by volcanic ash in which the soil had formed. I was referred to several references and invited to set in on geology classes and participate in field trips which I eagerly accepted. There was a lot of geology in Arizona that I had never seen while in Wisconsin.

In Arizona there was limestone, that I always thought was in level beds that was ‘wrinkled’ as the Colorado Plateau uplifted (left photo above), there were thick beds of volcanic ash that more recently fell on the land (center photo), and thick exposures that revealed at least 4 buried soil profiles (right photo).

There were a lot of things going on before the landscapes formed by the Wisconsin Age glaciers had formed the landscapes and soils in Wisconsin. Perhaps these Arizona experiences were unique to arid areas but did they influence soils in more humid parts of the world? Had other parts of the world not subject to the blending by relatively recent, Pleistocene glaciers undergone geologic traumas like I had seen in Arizona?

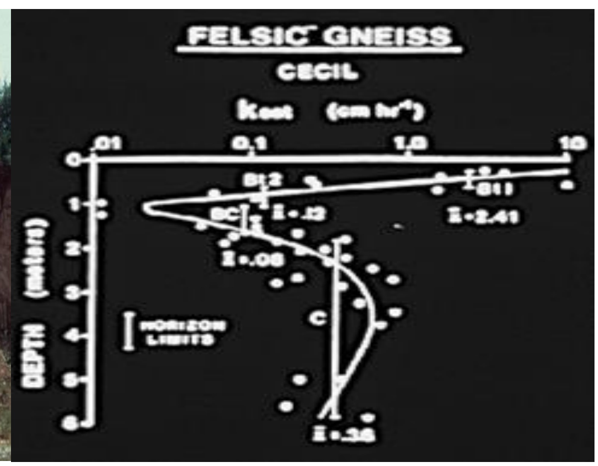
Over the next few years I had ample opportunities to observe non-glaciated parts of the world in the Eastern United States, South America, Africa, and Asia. In most cases the areas were in humid climates and geologic features were not as readily seen as in the arid Southwestern United States.


The eastern part of North Carolina provided some more upsetting features. Coastal plains were, in my mind supposed to be below upland and near the coast. However, over 100 miles inland coastal plain sediments were on top of weathered residual granite rock. As seen in the left photo above a four foot Ultisol solum (yellowish) rests abruptly over reddish clay weathered from granite. In the rolling landscape along the fall line soils (Kandiudults) developed in coastal plain deposits were present on the highest parts of the landscape while on the side slopes redder and higher clay content soils (Kanhapudults) were present. Ray Daniels pointed out that the area had been eroding for about 5 million years and coastal sediments that once covered large areas had been eroded except on the highest, level areas. Further east coast sediments were much thicker as seen in the center photo above. Exposures are not easily found but many of the sediments are cross bedded deposits of contrasting textures attesting to deltaic depositions while some strata are level bedded. Rather uniform soils (Paleudults) were present over most upland. Geologists report that the coastal sediments attain a thickness of 10,000 feet near the Atlantic shore. That is about twice as thick as the sediments exposed in the Grand Canyon providing an association of geologic processes. The tectonic uplift I had been exposed to on the edge of Colorado plateau in Arizona was repeated when I was shown a vertical slab of limestone with clearly visible ripple marks, upper right photo at an elevation of about 13,000 feet in the Andean mountains of Peru.

I had read about uniformitarian concepts and now they took on greater significance.

In the piedmont physiographic province of North Carolina and elsewhere in the Southeastern USA a feature I had not seen in Wisconsin or Arizona impacted. It was called saprolite, or in horizon nomenclature Cr.



Cr horizons a few inches thick had been observed but largely overlooked where Aridisol profiles were formed over granite rock in Arizona but in North Carolina saprolite material was several meters thick below Kanhapludult solums and underlying hard felsic rock, i.e. R horizons. As seen in the left hand photo above rock-like structure was apparent directly below the solum. However, this rock-like appearance was deceiving. It could be easily penetrated with a shovel or an auger. Further study revealed that the bulk density of the material was usually between 1.3 and 1.5 grams cm^{-3} whereas the underlying rock it physically resembled had a density of 2.65 grams cm^{-3}. Particle size analyses revealed textures from sandy clay loam to sand with clay contents decreasing with depth. Only small amounts of silt were present. In studies to determine the feasibility of using such sites for septic drain fields the saturated hydraulic conductivity was determined. As seen in the right hand graph it was surprising to find that the slowest conductivity was not in the Bt horizon that contained 60% clay but in the upper part of the saprolite, the B/Cr horizon with less than half the amount of clay as in the Bt horizon. Thin section studies revealed that in the upper portions of the saprolite clay skins filled the large pores in the rather rigid saprolite matrix apparently making that layer more restrictive to water flow than in the strong blocky structured Bt horizon. Ok, but what had happened to reduce bulk density in the saprolite?

A paper by Judson and Ritter (J. Geophysical Res. 69:3395-3401, 1964) wherein they summarized USGS data on solid and dissolved material in the major rivers in the USA provided an answer. Atlantic and Eastern Gulf coast rivers contained more dissolved material than solid material, i.e. more material was dissolving than eroding in those watersheds. All other watersheds, except the Colombia River in the Northwest removed more solid material than dissolved material.

Water balance calculations indicate that the piedmont regions of the Southeast annually receive about 15 inches of precipitation above potential evapotranspiration demands. The ground water that eventually enters the rivers was dissolving the more soluble minerals and bases in the bedrock leaving behind the more resistant minerals to maintain the structural integrity of the rock. As the upper layers of the saprolite were invaded by plant roots the rock structure broke down and soils, Ultisols were formed in material nearly depleted of easily soluble minerals. More fertile and mineral rich soils never had a chance to be present in such material. There was no transition from Alfisols to Ultisols as suggested by some authors,

The geologic features abstracted above had developed over thousands to millions of years. Was there present day evidence of the processes that took place during these time spans? The time scale of an individual or even human recorded history is but a flash in the time scale of earth’s history. If features could be found that demonstrated uniformitarian concepts it should be possible to see features that demonstrated the tectonic uplift and erosional processes that took place as these features were formed. Several observations come to mind.

On the rapidly, in a geologic time scale uplifting island of Madagascar, upper left photo numerous large gullies are highly visible in the savanna covered hills. There is no evidence of human land use abuse and a closer look detects that these gullies occur on the convex portions of the hillsides and result from the under cutting of the base of the slopes as rivers and streams dissect the landscape. In the Appalachian mountains of North Carolina, center photo above rotational slumps are prevalent at the base of the mountain slopes. Similar slumps are also present in Madagascar. Chimney rock, upper right photo is not rock but a spire of sediment that is the last remaining remnant of a disappearing land surface the material of which it was composed now deposited in the grass covered surrounding area.

As all of the above scenarios of erosion are taking place the eroded material must sediment some place.

Overviews of the sedimentary processes are readily seen from the air in the upper portions of the Amazon basin. In the upper left photo, point bar sand deposits, seen as white areas in the river form as the river flows around meander bends. As rivers deepen old meander positions laterally traverse an area leaving cross-bedded patterns of sandy levee ridges and finer textured lowland as seen in the center photo above. In some areas old meanders are cut off from the flow of the river and leave ‘horse shoe’ lakes, upper right photo in which level-bedded clayey sediments are deposited.

I now understand the sometimes cross-bedded sediments and sometimes level-bedded sediments of contrasting textures seen in the coastal plains of North Carolina.

During the years the above observations of parent materials, and associated climates, vegetation, topography and time scales were made as sidelights to what I was really looking at, i.e. soils. What I saw shook my long held belief that the climatic factor of soil formation would overcome everything else in the determination of soil properties.

Histosols were supposed to be black and present in depressions. I had mapped many acres of peat and muck, which was before they were called Histosols in Wisconsin.



However, on the broad, level coastal plains thick Histosols were present on the highest elevations. These Saprists, upper left photo had ‘grown’ and over time covered trees that had preceded them by growing in mineral soils. After the Histosols became too thick for the tree roots to reach the mineral soils they were replaced with swamp grasses, gall berry, and blue berry. When first exposed on ditch banks they appeared reddish in color but turned black as the organic compounds oxidized. These soils are extremely acid, pH values 3.5 to 4, C/N ratios of 30 to 40 and had saturated hydraulic values near zero. In an isohyperthemic soil temperature regime and ustic soil moisture regime near Brasilia, Brazil Saprist profiles were formed on 15 percent slopes, seen as a grass covered mount in the center photo above. These profiles were underlain by reduced oxic horizon mineral soil material, right photo above but saturated by seepage from a higher elevation.

Histosols form in aquic soil moisture regimes regardless of ambient atmospheric climatic conditions or topographic position.

For sure I found the red, acid, Kanhapludults like the Cecil soils (left photo) formed in the granite rocks in the piedmont physiographic provinces in Southeastern part of the United States. But, there was also the shallow Entisols formed over calcareous chalk in the Black Belt of Mississippi and Alabama (center photo). Perhaps there were some differences in climate, but not much. Then in Brazil there were Mollisols abruptly adjacent to Oxisols as seen in the right photo with calcareous sandstone showing in the lower right of the photo and red Oxisols in the valley. Had not these humid areas been classified as Pedalfers by Dr. Marbut? Had he not been aware of such soils in the humid areas? A rereading of his lectures assured me that indeed he was well aware as he cautioned his students not to take the Pedocal and Pedalfer separation as absolute and remember the Penn Series in North Carolina where carbonate was present in the subsoil. The Penn soil, now by a different name formed in limestone derived sediments in the Dan River basin still has carbonate in the subsoil.

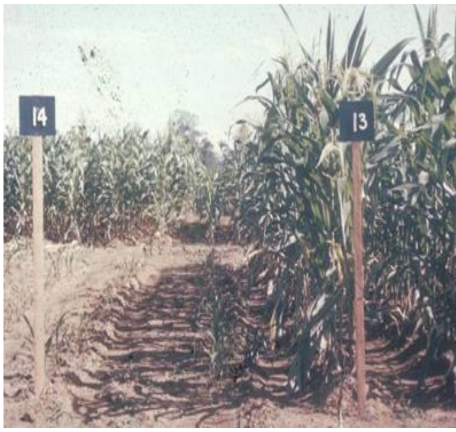
Also, there was the last paragraph in the 1941 book, Factors of Soil Formation by Dr. Jenny where he wrote that the soil forming factors related well to the soil properties in the Midwest of the United States but attempting to apply them on the Pacific coast often led to frustration.

Yes, the leading soil scientists were well aware of limitations embedded in their writings but I had accepted the clearly presented relationships of soil formation, especially those related to climate, organisms, relief, and time and neglected to fully inject the influence of parent material. It was an easy thing to not fully realize that at the time of Marbut and Jenny when the data available to them was almost entirely from Europe and Midwest, glaciated regions of the world. Dokuchaev and Glinka had similar limitations. The contrasting soils in the tropics were dismissed as 'tropical soils'.

Many soils I found in the non-glaciated areas of the world did not fit well into perceptions from the Midwest. However, Soil Taxonomy forced soil science to concentrate on soil properties not concepts of soil genesis and geography. After traversing tropical latitudes and finding soils with the same chemical, mineralogical, and physical properties as those I had studied in temperate latitudes I came to the following conclusion.

There was only one soil property that defined almost all of the soils in tropical latitudes, '<u>Iso-soil temperature regimes</u>'. With the exception of the Oxisols, soils in tropical latitudes had nearly identical counterparts in temperate latitudes.

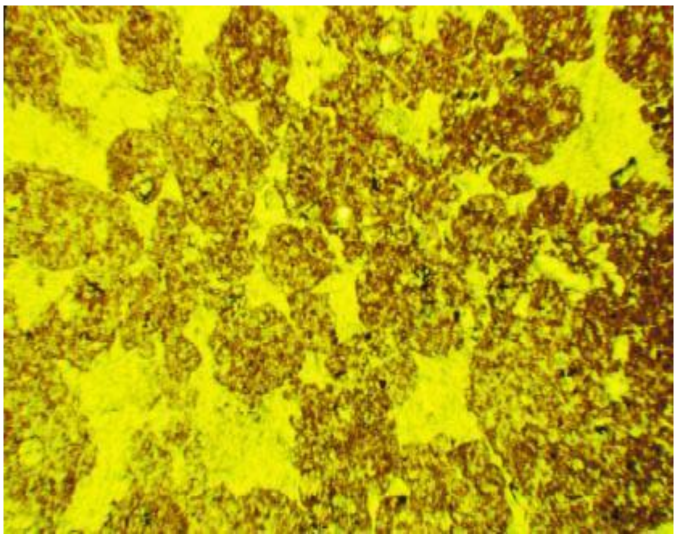
Aided by, or more correctly stated 'guided by' several excellent graduate students I had years of association with Oxisols in South America, Africa and Asia. Oxisols were the iconic 'tropical soils' in much of the soil science and geography literature. Oxisols, or associated names such as Latosols, Laterite, Lateritic, Etc. appeared to occupy large areas in tropical latitudes and were often condemned as being worthless and in danger of becoming bricks if cultivated. Many authors attributed their formation to intense weathering under hot humid climates. However, Van Wambeke found that Oxisols comprised only 23 percent of the tropical land area and more recent studies have identified Oxisols in all soil moisture regimes from aridic to perudic and aquic. Because of their low cation exchange values Oxisols were considered infertile and not capable of supporting human food crops.




Such opinions were understandable when the first unfertilized and unlimed planting of crops on Haplustox near Brasilia resulted in barren ground like plot 14 seen in the left photo above. However, some areas of Ustox, Eutrustox were being successfully farmed as seen in the center photo above. This photo was taken in 1968 and deserves special significance because such a scene is probably no longer present in Brazil. Note the palm trees in the background. Early European settlers in Brazil found that soil under forest vegetation was good for crops. To visually convey the value of their land they left the palm trees when clearing the forest. Over the years since 1968 the palm trees have died or have been removed to make way for the use of large farming equipment and are no longer seen. Also, I should add that most forests on the Oxisols with high base saturation percentage have also disappeared. A Eutrustox profile is pictured on the right above. This profile had a base saturation percentage of over 90 percent at all depths to 2 meters. The profile had been cultivated with large tillage equipment for 15 years and showed no signs of hardening except for a slightly denser plow pan. As a sidelight, the 1969 manuscript of our work was rejected by reviewers because they could not believe a soil could have a low CEC and a high base saturation percentage. It was published in Brazil. This site in the western part of Minas Gerais had Eutrustox abruptly abutting low base saturation Haplustox. Ancient volcanoes had spudded basalt lava over low areas and subsequent eons of erosion had reworked both the basalt and the adjacent acidic rocks. The sediments derived from basalt retained high base saturation while the soils in the reworked acidic material had base saturation percentages around 10 percent.

How could some soils retain bases while adjacent soils with the same climate, slope, and texture loose there bases?

Kubiena had once written that micromorphology added a visual dimension to physical and chemical measurements of soil.

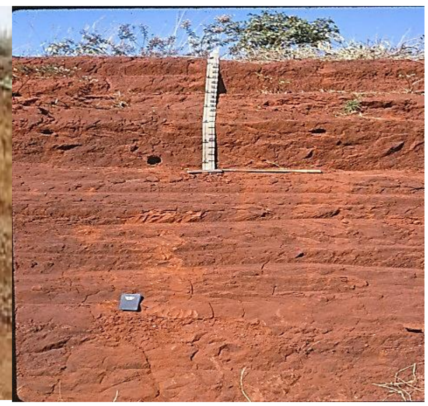


Thin sections of oxic horizon material, (above photomicrograph) revealed views that were quite in contrast to argillic horizons. Instead of ped faces coated with clay skins the peds were granular loosely packed with large voids between granules and there were no clay skins. When hand-texturing the oxic horizon material in the field one had to wet and work the material for up to five minutes to get the true feel of the some 60% clay. At lesser times the 60% clayey material felt like sandy loam. The 15 bar water content was over 20 percent and the 1/3 bar water content was only slightly higher, i.e. very low plant available water content. Saturated hydraulic conductivity was comparable to that of sand textures. Clay mineralogy was kaolinitic and the sand was rounded quartz. There was never much silt.

It appeared that in such material leaching water never contacts the small, 15 bar water retaining pores in the interior of the clayey granules. The base ions of Ca^{2+}, Mg^{2+}, and K^{+} present in the sediments derived from basalt still resided on the exchange sites of the kaolinite within the strong granules while in similar oxic horizons in sediments derived from acid parent rock saprolite few bases had ever been present.

After numerous excursions and studies of Oxisols most, but not all were present in alluvial materials.

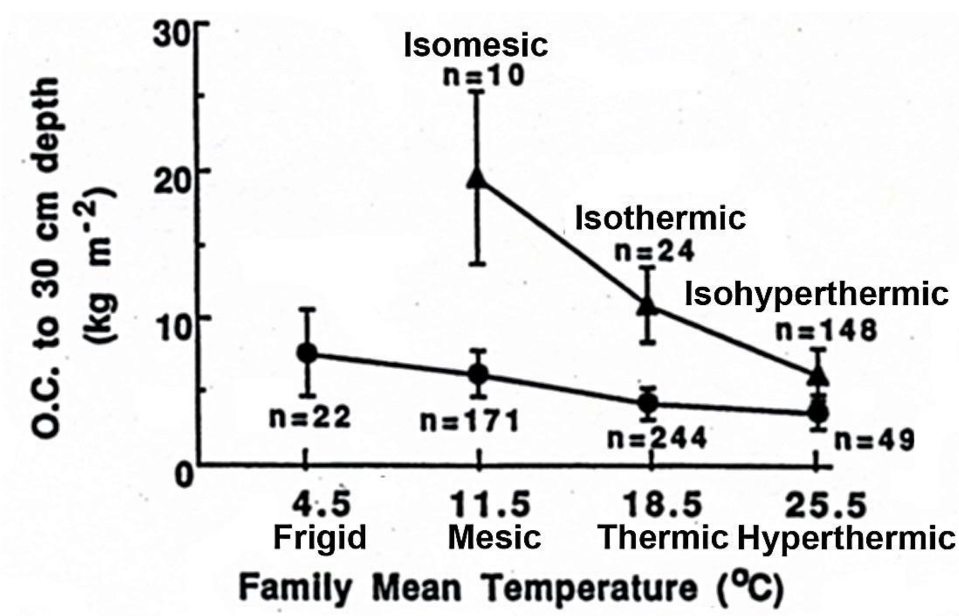




Near Brasilia, sites near the center of the continental divide between the Amazon watershed to the north and the Paraná watershed to the south road cuts reveled layers of sediment overlying metamorphic rock saprolite as seen in the left photo above. Below relatively low escarpments gravel layers consisting of both iron cemented gravel and quartz gravel were frequently exposed in road cuts, center photo. The further we traveled south of Brasilia the exposures were thick and lacked any disenable contrasting layers as seen in the right photo. (Caution, always be aware that road cuts become coated with black soot from the heavy diesel truck traffic. Note brighter red color where we scraped the surface.)There are an estimated 400 million acres of such sediments in central Brazil and the lower Amazon Basin. Professor Orme, UCLA attributes these sediments to persistently warm humid climates of Cretaceous and early Cenozoic time. (in Veblen, Young and Orme, eds. 2007 The Physical Geography of South America. Oxford Univ. Press) Whatever the geologic history, the sediments are composed of kaolinite, gibbsite, iron oxide clays and quartz sand. In many areas the Oxisols often are composed of more than 60 percent clay while in other areas the sediments are loamy sand or sand texture. This creates a rather interesting conflict within the common soil genesis interpretations associated with the Orders of Entisols and Oxisols. Quartzipsamments and Haplustox are found spatially abutting on mutual landscapes. Is there a common genetic thread that can explain Entisols, recent soils with Oxisols, highly weathered soils?

If parent material is composed of material that cannot be altered by soil forming processes its features cannot be changed in response to soil forming factors now present. Gibbsite, kaolinite, and sand-size quartz all fit the bill and so do iron oxides if not exposed to reducing conditions. Quartzipsamments and Oxisols are present in all soil moisture regimes from aridic to perudic. They are pedogenetic siblings in the family tree of inert parent material.

Along the way happenstance events reveled another soil property related to 'tropical soils'. When the Soil Science Society of America asked me to write a paper on how global warming would affect soil properties I enlisted the help of John Kimble and others. One soil property, soil organic carbon content was almost certain to be affected by warmer climate so I asked John to query the data in the Lincoln lab as to organic carbon content of well drained soils by the soil temperature regime criteria. When data was graphed to the midpoint temperature of each soil temperature regime the following graph was a surprise.



The relationship of organic carbon content in non-iso soil temperature regimes confirmed the relationship presented by Jenny but equivalent mean annual temperatures in iso soil temperature regimes were all significantly greater. Why?

Ambient soil organic carbon (SOC) content represents a steady state between organic matter production and decomposition. On the production side it is probable that vegetation in iso areas grows all year which is not true in all but perhaps the hyperthermic soils. Also, several of the isothermic sites also had ustic soil moisture regimes during which plants were not growing. All data indicate lower SOC in warmer climates where growth rates are greater and in non-iso latitudes growing seasons are longer than in colder sites. The production side of the steady state does not seem to account for the observations. On the decomposition side of the equation non-iso sites have to have much warmer periods during the year to equal the mean annual temperature of the iso sites. Also, non-iso sites have significantly longer daylight hours in the summer that would allow greater soil heating than in the iso, tropical sites. One can deduce that more rapid decomposition engendered by higher temperatures, albeit only for a few summer months is most responsible for the lower SOC content in non-iso soil temperature regimes. This is in line with the Van't Hoff relationship of doubling or tripling chemical reactions for every 10 ^{o}C temperature rise.

While on the subject of soils in tropical latitudes I would suggest that those responsible for Soil Taxonomy consider rethinking the definitions of both the soil temperature and soil moisture regimes in tropical latitudes. In iso soil temperature regimes reliable seasonal moisture controls the planting and harvesting of food crops. In non-iso regimes these activities are controlled by seasonal temperatures. The present ustic soil moisture regime definition in iso soil temperature regimes includes soils with reliable moisture for both one and two crops annually. In some areas two crops are consecutive during the year and in other areas like much of east Africa the two growing seasons are separated by a period of dryness. Also, the perudic soil moisture regime

essentially precludes grain crops due to a lack of dryness to cure the grain. Although used in Oxisols soils in other Orders are similarly affected.

The present class limits for iso- soil temperature regimes duplicate those in temperate latitudes and reflect growing season limits for major crops like citrus, cotton, and corn but do not appear definitive for important crops in tropical latitudes. The 8 ^{o}C MAST class limit for iso-frigid families is too cold to delineate the temperature limit for potatoes, a main food crop for indigenous farmers in tropical mountains. The soil temperature at the upper limit of potato fields, as seen near to top of the photo from Ecuador below is 10 ^{o}C. Similar observations have been made in Venezuela and Columbia.

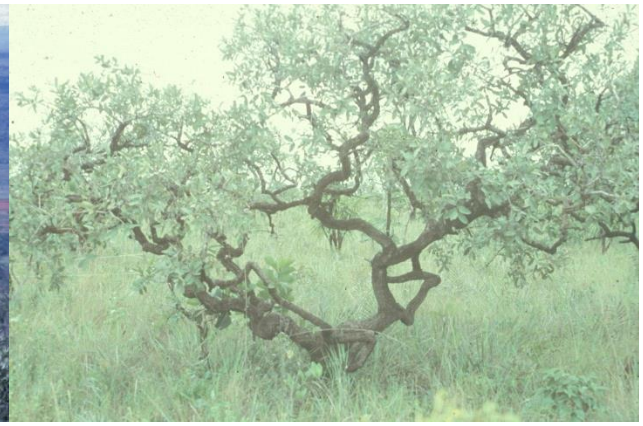
A SOIL IS; A SOIL DOES; A SOIL CAN DO

When not surrounded by like-minded soil genesis and classification professionals I was seldom questioned about how I thought a particular soil had been formed but rather questions of what to do with this kind of soil. I tended to pass such questions off as not being my obligation. Then there was the blunter question, why do we classify soils? On several occasions I had heard Guy Smith raise the following question of a proposed taxa definition, “How will this definition allow us to make a better interpretation?” That question prompted the above heading. We classify what a soil is. Creating quantified ranges of a soils chemical, physical, mineralogical, temperature, and moisture classification creates reagents within the spectrum of soil. As a chemist uses identified reagents to conduct experiments a taxon of soil is a reagent that interacts with natural ecosystems and is a reagent in experiments with managed ecosystems, most specifically agroecosystems. What a soil does can be is determined by observing associated natural ecosystems and the human management. What a soil can do often differs from what it presently does because catastrophic natural events or human activity has altered vegetation or local economic and political infrastructure limits indigenous humans from changing present practices. Also, there is the possibility that comprehensive research has not been done to explore the range of possible uses specific kinds of soil are capable.

As I observed a broad perspective of how closely temperature and moisture affected soil use I slowly began to understand why Guy had insisted on incorporating quantitative criteria of soil moisture and soil temperature in Soil Taxonomy. I had not been fond of such criteria when faced with hyperthermic to frigid soil temperature regimes and aridic, ustic, xeric, and perhaps udic soil moisture regimes in Arizona. Hyperthermic defined citrus growing areas but most of the other temperature and moisture regimes were on steep terrains where profiles had scant morphological differences and were of little use except rangeland. Only when I began to observe broad areas of the world and how soil properties affect the management techniques farmers used did I develop an appreciation for the interpretive value of a soil classification that quantitatively addressed a soils ability to supply water and temperature.

A Saga of What a Soil Does to What a Soil Can Do

There appeared no greater challenge than attempting to find out what Haplustox soils could do. In Brazil the Eutrustox were being successfully cultivated but the extensive areas of Acrustox and Haplustox supported no farming. The reagent soils in this saga are Fine, kaolinitic, isohyperthermic Typic Haplustox and Typic Acrustox on sites we selected near Brasilia, the capital of Brazil.

These areas with nearly level to rolling topography, upper left photo were vegetated with seasonal grass and scrub trees as seen in upper right photo known as cerrado. The isothermic to isohyperthermic soil temperature regimes and ustic soil moisture regime that varied somewhat from 6 months wherein precipitation exceeded potential evaporation and 6 months of almost no precipitation. The grasses, as seen in the right photo during the rainy season appeared to offer excellent grazing however, experience among ranchers who had attempted to graze cattle had resulted in failure as cattle died from weakened bones when grazing on the calcium and phosphate deficient grasses. During the dry season wildfires were rampant over the area and thought to be responsible for the knurly appearance of the fire resistant woody species. The cerrado vegetation was popularly known as a place the loose cattle rather than a place to graze cattle.

Could these soils be utilized for grain crops and productive rangeland?

In 1971 we, North Carolina State and Cornell University soil science staffs set about experimenting on a site near Brasilia. Lab studies revealed that P fixation was a major concern. Fertilizer rates as high as 800 pounds of elemental P per acre were projected to be necessary to provide adequate available P for crop growth. Earlier studies by FAO scientists had limited P fertilizer rates to a maximum of 40 pounds per acre, considered the economic maximum a farmer could afford. All field trials failed and these soils were declared useless for crop production. Aluminum dominated the exchange sites and had to be neutralized with lime. In addition micronutrients, especially Zn and Cu appeared to be limiting. Thanks to the foresight of Gene Kamprath field experiments were conducted that included deep placement of lime with these seemingly uneconomical rates of P fertilization, and were successful. The photo below is of demonstration plot showing soybeans planted on Acrustox soils. The two rows of soybeans, in the foreground were planted with no lime or fertilizer. The main soybean field has been limed and fertilized according to rates established by earlier experiments. In the background is cerrado vegetation that was cleared for the first planting on this field.

Although weather records indicated adequate rainfall during the rainy season prolonged rainless periods do occur and the limited rooting depth of the limed topsoil in the low available water holding capacity of the Oxisols severely reduces yields in some years but this could be alleviated by deeper tillage to incorporate the lime and negate the aluminum toxicity to a greater depth. Within a year or two it was determined that while the extremely high rates of P fertilization were necessary to overcome the P fixation, apparently the surfaces of the iron minerals became saturated and annual P requirements were no greater than in any other soil, i.e. about 25 pounds of P per acre to replace P harvested in the grain crop. Other rather unexpected things happened. Calcium was moving down below the placement depths in the limed soils thereby increasing the rooting depth and alleviating the effect of drought during the growing season. In acid soils the CEC sites are saturated with Al^{3+} that must be replaced by Ca^{2+} to accommodate grain crop roots. Calcium does not translocate in the plant and must be present in soil for the roots to elongate. With lower CEC less Al^{3+} is present and thus a lesser lime requirement. About 1 ton of lime per acre is required per cmol of Al^{3+} Kg^{-1} soil. Also, low CEC means less retention of Ca^{2+} and it more readily moves down in the profile enlarging the rooting volume. This effect was especially noticeable in the Acrustox where the CEC in the subsoil is extremely low, often zero.

The dogma that a high CEC was necessary for a good agricultural soil was not true. In fact the low CEC of the Oxisols was an advantage to the management for grain crop production.

To facilitate more rapid downward movement of Ca^{2+} applications as gypsum proved beneficial and to recognize the limitations the Family reaction class ‘Allic’ was established in Soil Taxonomy for Oxisols that had a 30 cm or greater thickness within the Family control section with more than 2 cmol of KCl extractable Al per Kg soil. Such subsoil layers most often are related to higher than normal organic matter contents that contribute to CEC. This is contrary to the dogma that organic matter benefits soil because it increases CEC but when the CEC is occupied by Al^{3+} that only increases management costs for extra lime and retards downward movement of the $Ca^{2+.}$


Except for a few subsistence farmers on rare sites of Eutrustox or Alfisols there was no farming or ranching in the cerrado when I traversed parts of the area in 1968 and 1973. In about 1985 a few successful commercial farmers from Southern Brazil visited our research site near Brasilia and after seeing our results purchased large acreages of ‘worthless’ cerrado for about $30 US per acre. They planted soybeans and upland rice crops using the most modern planting and harvesting equipment and the ‘recipes’ of liming and fertilization that had proven most successful in our research. The results are seen in a farmer’s soybean field, upper left photo. By then EMBRAPA , the Brazilian equivalent of the ARS in the United States had greatly expanded the initial research station near Brasilia and staffed it with competent soil scientists and agronomists. More commercial farmers from the south of Brazil recognized the potential and invested in ‘cerrado’ land for their sons and daughters. Banks were at first reluctant to finance farming enterprises wherein initial fertilizer costs, that they considered annual expenses to be more than ten times the cost of the land but slowly came to realized that these initial fertilizer and lime costs were capital investments and after production was established annual fertilizer costs were no more than experienced elsewhere. The result has been nothing less than spectacular. As seen in the upper right photo, which is clearly staged for the website showing some 32 self-propelled combines harvesting soybeans and followed by no-till planters is not a great exaggeration of what is now going on as grain production expands in the some 400 million acres of Ustox in central Brazil.

Several soil properties as defined in Soil Taxonomy identify the success of grain farming on these once considered useless Oxisols.

The Oxisol definition dictates soils of near uniform textural profiles. Such profiles, with their strong granular structure rapidly infiltrate water, have little surface run off and erosion, and the soils freely drain enabling rapid cultivation after rain events. The ustic soil moisture regime combined with the isothermic and isohyperthermic soil temperature regimes assures a prolonged period of dry conditions wherein ripened grain can be harvested over a long period of time. This allows for maximum efficiency of harvesting equipment and reduces drying costs experienced in non-iso soil temperature regimes wherein farmers must rush to harvest before the onset of winter and rely on artificial drying facilities to reduce moisture content for grain storage. This feature is credited with a 50 cent per bushel cost of production advantage over the grain production areas of in the United States. Although not a criteria for Oxisols their presence on nearly level to gently rolling topography accommodates efficient mechanized farming equipment and highway construction. The magnitude these developments are attested to when one realizes that the 400 million acres of cerrado vegetated Ustox is equivalent in size to about 5 Midwestern states in the USA. Archer Daniel Midlands and Cargill have invested billions in establishing terminals to receive the grain and the overall economic and political stability of Brazil has greatly improved as this frontier, equivalent to the opening of the prairie states in the USA has been initiated.

When demonized for their lack of native fertility it should be remembered that even the most naturally fertile soils are annually fertilized to sustain high levels of productivity. It is not native fertility that sustains high yields in any soil. This often ill appreciated fact is illustrated by comparing how corn yields and fertilizer rates changed from about 1920 to 1980 on some the most fertile Mollisols and less fertile Ultisols in the table below. When yields were low the unfertilized Mollisols out yielded the slightly fertilized Ultisols but when attaining high yields more fertilizer was applied to the Mollisols than to the Ultisols because they were removing more nutrients with each crop.

Historical Comparison of Average Farmer Fertilization Rates on Norfolk (Ultisols) and Tama (Mollisols) Soils in the US

(Original data from Soil Survey Reports and Unpublished Agricultural Extension Service records.)

	Element	Norfolk Soils (NC)		Tama Soils (IA)	
Year		1925	1983	1919	1979
Corn Yield (Bu Ac^{-1})		32	110	42	130
Fertilizer Rate (Lb Ac^{-1})	**N**	32-47	120-158	0	150-180
	P	3-5	18	0	30-48
	K	5-10	67	0	67-99

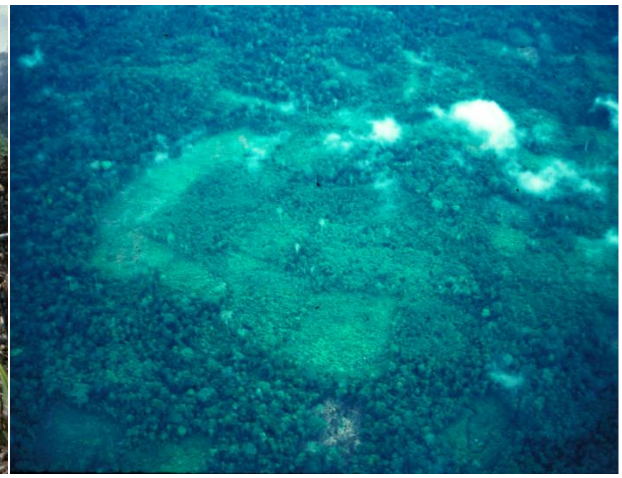
The difference between what a soil does and what it can do was vivid on an interstate correlation trip between Arizona and California. We were to agree on land capability classification of soils. Soil Taxonomy was not the law of the land but I think the soil in question would classify as Sandy-skeletal, calcareous, hyperthermic Typic Torripsamments. In Arizona with no access to irrigation water and 2 inches annual precipitation it was class VIII. In California, with an ample supply of cheap irrigation water, a drainage system to remove leached salts for discharge into the Salton Sea the soils supported lush citrus orchards and was reported to have the highest income per acre of any land in California. What a difference technology and infrastructure makes.

What a soil can do cannot be determined by what it presently does.

Saga of Slash-and-Burn

Best known as ‘shifting agriculture’ or ‘slash-and-burn’ and several other names multitudes of indigenous humans subsist by cutting and burning tropical forests to prepare areas for growing food crops. Cutting, drying and burning tropical jungles to prepare land for planting food crops has long been discouraged by ‘enlightened’ academicians. Many studies have established that a high percentage of essential elements are volatilized or otherwise lost in the fires. More recently some think the practice is a cause of global climate change. There must be a better way.

My first venture into the slash-and-burn culture came in 1971 in the Amazon basin of eastern Peru. Pedro Sanchez and I were to select a site for an experiment station somewhere within a 10,000 hectare tract of land near Yurimaguas, Peru. The reagent soils at the selected site are Fine-loamy, siliceous, subactive, isohyperthermic Typic Paleudults. With only one un-surfaced road traversing the area it was clear that the site needed to access the road for logistics. The area was rather sparsely settled by subsistence farmers practicing slash-and-burn agriculture. To aid in our traverses we hired three local men, all with slash-and-burn experience to cut trails and dig pits for soil examination. To my surprise the pits revealed soils quite different from the Oxisols I had worked with in the savannas (cerrado) of Brazil and in most cases were morphologically nearly identical to the Paleudults on the coast plain of North Carolina. While digging a pit for my examination we inquired of our laborers if this was a good site to cut, burn, and plant a crop. As they stopped digging and discussed our question I noted that they always looked upward and never once directed their attention to the soil. After a couple of minutes of discussion they declared the site as not suitable to clearing and planting, which I duly noted by my profile description. Later in the day at some distance from the earlier pit but in a similar landscape we again asked the laborers if this was a good site for a field. Again they directed their attention upward, ignoring the soil and declared this was a good site for a field. My profile description was almost identical to the earlier site the labors had said was not a good site. I passed over their evaluation as resulting from a lack of a formal education about the value of soil. As I was to appreciate during the next few years the laborers ‘practical education’ in soil science was far superior to my ‘formal education’ when it came to understanding why subsistence farmers have used slash-and-burn in their quest to grow human food crops.

Observing the burning, left photo it is noted that the small branches are carefully spread to cover the soil surface before the dried material is fired. In the right photo an area of jungle, as viewed from low altitude has an array of rectangular patterns resulting from a sequence of clearing, burning, cropping for a couple of years, and abandonment to native regrowth for about 20 years at which time the sequence can be repeated.

The care in spreading the small branches by the experienced slash-and-burn farmers in Peru left a uniformly black, ash covered surface after burning as seen in the left photo. Later, observing inexperienced slash-and-burn farmers in Indonesia, perhaps aided by government supported mechanical clearing that resulted in non-uniform ash covering the growth pattern of upland rice is apparent in the upper right hand photo. Where there are ashes, as witnessed by the black soil surface the rice grows well; without ashes the rice will not make it.

I now know why the laborers in Peru looked upward to decide if a site was good for clearing. They wanted an abundance of small trees with small branches that would burn and yield an abundance of ash.

Drying is necessary for a good burn. A seasonally drier period is assured in ustic soil moisture regimes. In udic soil moisture regimes a near rainless period is necessary and in some years unsatisfactory burns result because the slash is too wet. Slash-and-burn is largely excluded from perudic soil moisture regimes. OK, that is part of the slash-and-burn story, but why the need to burn and why were areas usually ready for a second cycle of slash-and-burn after about 20 years which was a common value obtained by interviewing experienced farmers? There was no doubt the system worked and had sustained many generations in the upper Amazon basin.

Timing Requirements for Elemental Availability

Plant time	Plant parts	wt Kg ha $^{-1}$	Above ground Content of Elements Kg ha $^{-1}$				
			N	P	K	Ca	Mg
Rice 100 days	grain	5,380	56	10	9	3	4
	straw	5,610	34	6	65	10	6
	total		90	16	74	13	10
Pine 22 years	wood		57	5	35	52	14
	other		66	10	18	80	7
	total		123	15	53	132	21

Two items in the above table, derived from sources not directly related to tropical jungles appear related to answering these questions. One, rice and almost all human food crops grow in about 100 days or less and the period of nutrient uptake is probably on the order of 50 or less days. Plants only ingest inorganic ions thus burning immediately frees N, P, K, Ca, Mg, Etc. from the organic compounds in the litter, albeit with significant loses in the fire but burning the carbon causes immediate availability to the planted crop. The slow rate at which trees require nutrients as compared to human food crops as seen in the above table explains why they establish in abandon crop fields and after about 20 years will have accumulated enough essential elements in their above ground biomass to fertilized another one or two food crops if properly cut, dried, and burned. For several years I had observed abandon fields and read the horror stories about the complete ruination of soils by slash-and-burn farmers and knew that was not true. I was fond of saying that I usually had to run out of an abandon field because the native brush and trees would grow up my pant leg. Native brush and trees readily establish in soil too infertile to support food crops.

Slash-and-burn farmers are really expert chemists and botanists that know how to create plant available inorganic ions in a timely fashion to provide for the growth of human food crops.

As years passed and experience grew other aspects of slash-and-burn became apparent.


The first crops in a slash-and-burn farmer’s fields appeared to have less weed problems than experienced in research station fields. The farmers routinely planted their crop in the freshly burned fields with minimum tillage by simply punching a hole with a ‘planting stick’, as seen held by the farmer in the above left hand photo and covering the seed with a deft stomp of a bare foot. On the experiment station the soil was often cleared of large pieces of unburned wood and rototilled or otherwise tilled to prepare a seedbed resulting in the need to ‘weed’ the crop as seen in the right hand photo of a laborer weeding a crop of peanuts on the experiment station.

Fire killed the weed seeds near the soil surface therefore giving the planted crop a head start whereas

cultivation brought weed seeds to the surface where they rapidly germinated and competed with the planted crop.

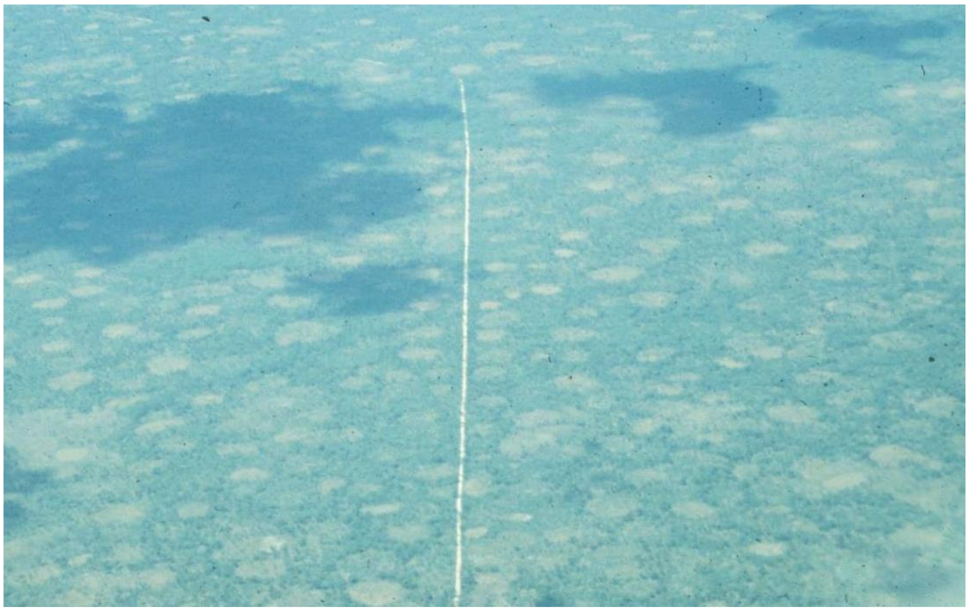
Thus far experience with slash-and-burn cultivation had been largely confined to udic soil moisture regimes with isohyperthermic soil temperatures and on naturally acid, low base saturation Ultisols in areas of rather sparse human populations and an abundance of land covered with tropical jungle vegetation. How did shifting cultivation fare in areas of relatively fertile soils and dense human populations?

On the flight from Uganda to Rwanda I was shocked to see almost 100 percent of the land surface covered by a typical slash-and-burn pattern of small fields and small, rectangular patches of rather small trees. Viewing this area on the ground, upper left photo it was apparent that almost none of the forested areas were more than five or perhaps ten years old. The human population density and competition for space to grow food was so great fields were not allowed to ‘rest’ for the approximately 20 years necessary to accumulate enough nutrients in their biomass and when burned there was not sufficient nutrients in the ash to grow a good yield of a food crop such as corn as seen in the right hand photo.

Although the soils in this area of the Rift Valley were Andisols and other soils naturally more fertile than the Ultisols in the Amazon Basin they could not sustain food

crop production via slash-and-burn if natural vegetative regrowth during a fallow period had insufficient time to accumulate sufficient nutrients.

While flying at low altitude over northern Zambia I noted an unfamiliar pattern of land use seen in photo below.



Upon examination on of the area on the ground I found the soils to be Ultisols with an ustic soil moisture regime, i.e. Ustults. Although the native vegetation was a form that could be called tropical jungle the size and density of the trees were both much less than in the udic soil moisture regime in the Amazon. The near circular pattern of clearing seen from the air was created by farmers as they cut the limited vegetation, piled it, and then burned it during the dry season to provide a fertilized area on which to plant their crop. The circular pattern would seem to result from the practical consideration that a circle is the geometric pattern offering the least distance to transport the amount of vegetation necessary to provide sufficient ash when burned.

Although the native practices may appear different the basic objective of slash-and-burn is to provide an adequate amount of plant essential elements in an inorganic form in the soil to satisfy the

intense rate of nutrient uptake required by human food crops. The fire is necessary to provide the rapid release of these elements from their carbon based compounds in vegetation and microbial decomposition is too slow for the requirements of food crops.

Having seen shifting cultivation on many soils that were almost indistinguishable from Ultisols that predominate the landscape in the Southeastern United States it seemed to be reasonable to assume that at one time slash-and-burn was widely practiced in that area.


Browsing old literature I found photos in a 1902 report to then President Teddy Roosevelt like the one on the left above. Such scenes are not found today but evidence of the practice is apparent and in the photo on the right where rectangular patterns of unmanaged vegetation on the hillsides are outlines of slash-and-burn fields abandon at different times. The soils in the above photos are mostly Dystrudepts but the same rectangular patterns of old fields are evident in many areas of the Ultisols dominated Southeastern United States.

Surely someone had written about slash-and burn in North Carolina.

Well, it was not by that name but the following, quoted from the printing of an 1822 speech by Professor Elisa Mitchell to the North Carolina Agricultural

Society, and reprinted in the North Carolina Dept. of Agriculture Monthly Bulletin No 15, October 1882 filled the bill.

"The soil of this State is pronounced, by those who have travelled extensively on both Continents, to be of a middling quality. It is of that kind which seems most to demand the employment of science and skill in its cultivation, and to promise that they shall not be employed in vain. Our grounds are neither so fertile that they will produce spontaneously what is necessary to the sustenance and comfort of our citizen, not so sterile that we have to abandon them in despair. When our ancestors landed on these shores, they had for ages been covered with a continued forest, the trees of which, as they decayed and fell, had deposited on the earth a rich bed of vegetable matters, which was ready to furnish the most abundant nourishment to any seed that might be committed to the ground. The first settlers, therefore had nothing to do but to select the most promising spots, clear away the timber, and loosen the soil, so that the vegetables to be grown could strike their roots into it. As the fertility which they had at first found was, in the course of a few years, exhausted, it became necessary, either to provide the means of renewing it, or deforest another tract and bring it under cultivation. As it was found the latter could be done at the least expense of time and labor, it was perfectly natural that the exhausted land should be thrown out, and fresh ground brought under tillage.

This process has been going on till most of the tracts whose situation and soil were most favorable to agriculture, have been converted into old fields and in our search after fresh ground to open, we are driven to such inferior ridge-land as our ancestors would have passed by as not worth cultivating. It is useless to complain of the course which our planters have pursued—they have pursued their own interest--and pursued it in the main with discretion and judgment. It were perfectly absurd to expect them to attempt to improve their land by the application of manures so long as they could obtain, at less expense, the use of that great store of vegetable matter with which nature had for many centuries been covering our country.

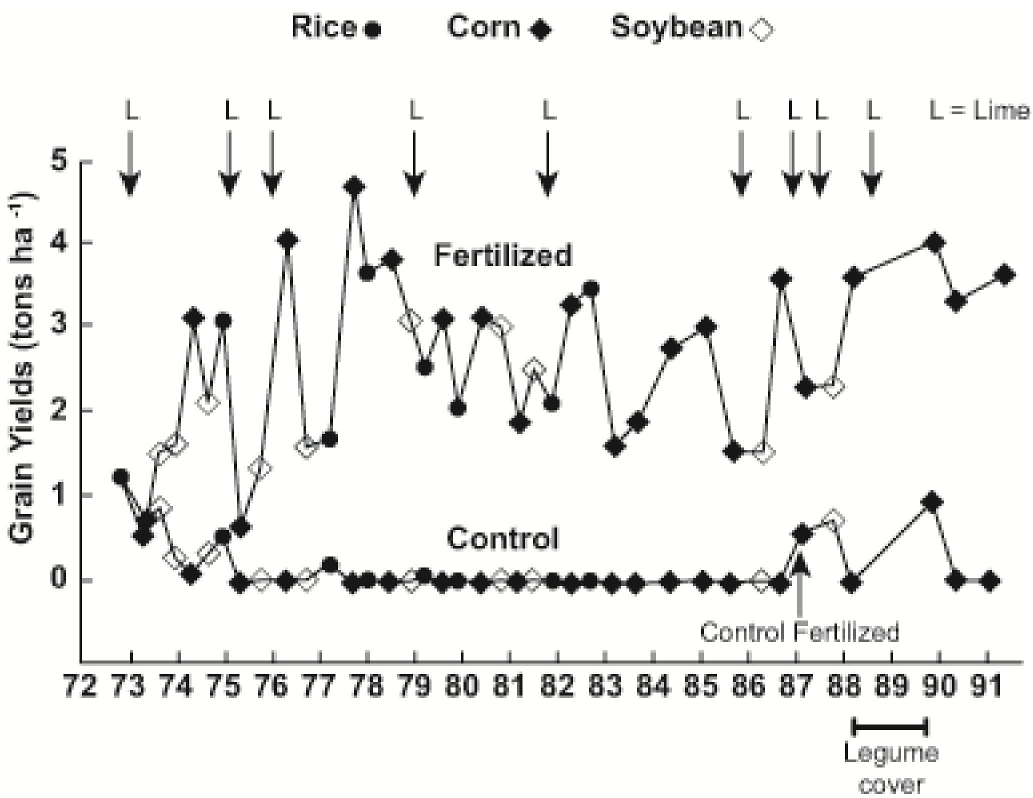
But, in the process of time, as this system goes on, the planter will look down from the barren ridges he is tilling, upon the grounds from which his fathers reaped their rich harvest, but which are now desolate and abandoned, and enquire whether he cannot restore to them their ancient fertility, at ales expense than he can cultivate those lands of an inferior quality, with which he is now engaged. Till he is driven by necessity to make this enquiry, we can hardly hope that agriculture will be studied as a science. The planter will not give us a patient hearing when we talk to him about manures. “

There it was, a vivid description of what we now call Ultisols and inferior steep slopes of Dystrudepts, upon which we still see the successions of natural vegetation invading the last abandon fields.

The manures of which Prof Mitchell wrote are now known as lime and chemical fertilizers that have enabled farmers to reclaim and the old fields on the more level areas of Hapludults, Paleudults, Kandiudults, and Kanhapludults, till them with powerful machines, and reap profitable harvests. The inferior hillsides of Dystrudepts are no longer cultivated.

If our soil classification is useful in transferring information it should be possible to duplicate what had been done over the years in North Carolina Ultisols and associated soils to the Ultisols in the Amazon Basin.

Fortunately, sequenced with the above observations we were able to maintain agronomic research on the Paleudult site we had selected near Yurimaguas Peru. The only taxonomic distinction between North Carolina and Yurimaguas was a thermic vs. an isohyperthermic soil temperature regime, respectively. As a small part of the numerous experiments conducted at Yurimaguas two side by side plots were cleared by slash-and-burn and then maintained for 20 years. In one plot complete lime and fertilizer applications were made utilizing the best interpretations of soil testing technology. In the adjacent plot no lime or fertilizer was ever applied. Both plots were identically cultivated and planted each year to two and sometimes three crops of adapted cultivars of corn, soybeans, and upland rice. The yield data is graphed below



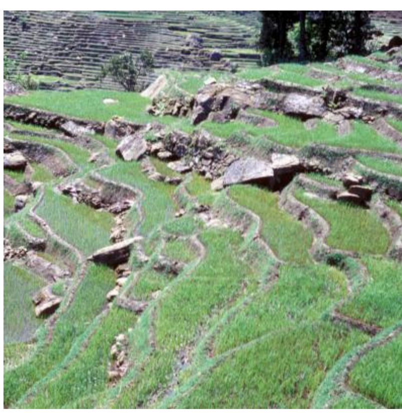
The time period of the study is indicated in 1900 years at the bottom of the graph. As seen in the graph the unfertilized (control) plot produced almost no yields after the first few years while after an uncertain benefit in the first few years the limed and fertilized plot sustained substantial yields. As in many experiments a couple unexpected events occurred during the 20 years. In 1987 a laborer mistakenly applied fertilizer to the control plot that resulted in some yield for the next two crops. From 1988 to 1990 there was terrorist activity in the area and we had to suspend experiments and recall our personnel for safety reasons leaving both plots planted to a legume cover crop. Upon our return in 1990 a small yield of corn was obtained as the legume cover crop was incorporated before planting. Subsequently yields in the control returned to zero. Several experiences marked the unimpressive results obtained the first few years of the experiment. Soil samples had to be sent to North Carolina for soil testing and a cargo plane carrying the samples crashed and the researchers had to fertilize and lime by ‘best guesses’. Also the lime available was calcitic and in1975 severe magnesium deficiency greatly reduced yields. Our meager benefits the first few years cast doubt on the feasibility of replacing slash-and-burn, shifting agriculture with continuous cropping. The experience brought to mind my grandfather’s expression of ‘taming the land’ from his early experience clearing land in Wisconsin. It takes time to ‘get things right’ when entering a new environment. Our experience brings into question a number of results from two-year foreign aid projects, a common practice among NGO and government programs.

Now, looking back after some 20 years has these results altered farming practices in the area? Only slight changes have resulted. The major limitation appears to be an infrastructure system that is inadequate to transport grain and supply farmers with what they need to sustain continuous cultivation.

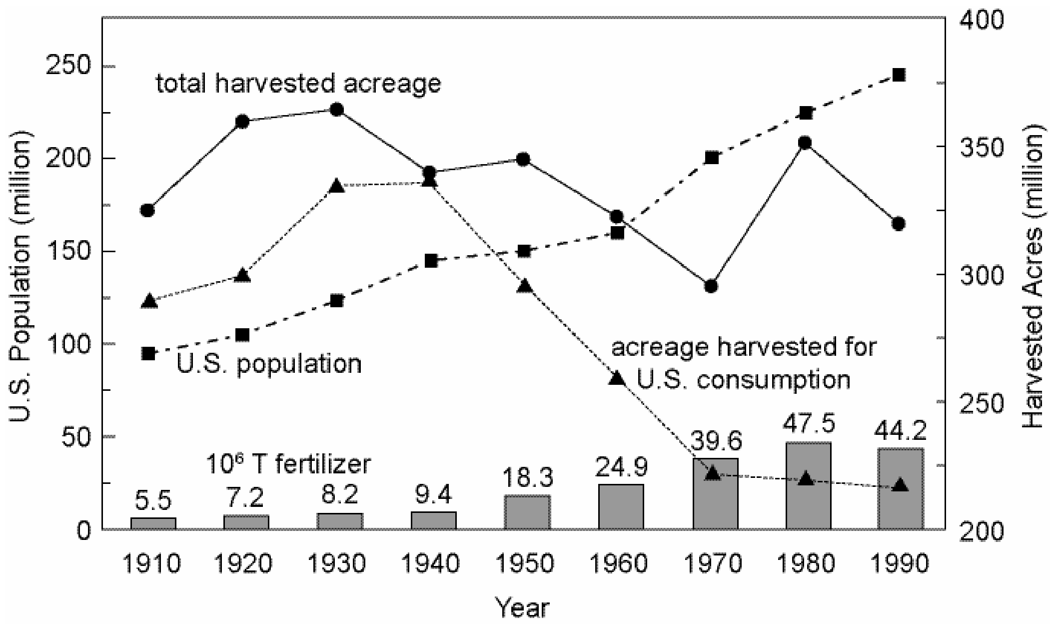

Stymied by road conditions as seen in the left photo above corn had to be bagged and loaded on by hand onto a river barge as seen in the right photo above. Not much profit results to the farmer. In many areas land improved by fertilizer has been acquired by ranchers as grain farmers found their operations unprofitable and moved deeper into the jungle to subsist by slash-and-burn technology. Beef cattle can be driven on the hoof to more reliable transportation. Meat is more valuable per pound than grain so is more profitable to transport to market. Unlike the experience in Brazil where infrastructure quickly followed grain production such infrastructure is much more difficult in the Amazon Basin. To the west the Andean mountains bedevil roads. The numerous rivers in the basin seasonally rise and fall with the seasonal rains. The amplitude on the main channel of the Amazon River is approximately 45 feet. The broad flood plains largely negate the maintenance of bridges.

The Paleudults and associated soils in tropical latitudes can support continuous cultivation but it takes more than farming practices to support commercial agriculture.

Having had the opportunity to observer similar soils under a variety of economic, social, and political circumstances I tend never to say never when asked to predict what a particular kind of soil can do. To be a devil’s advocate in a game of ‘what if’ consider what might happen to soils in North Carolina if the use of fertilizer was forbidden. Would hungry people terrace the Dystrudepts in the mountains as seen in the left hand photo below from Sri Lanka? Would the vegetation from the hillside Hapludults be gathered and composted to use as fertilizer for food crops in the valleys, leaving the hillsides to erode as seen in the center slide below from the People’s Republic of China? Would our now protected coastal wetlands of Aquepts and Fluvaqents be converted to rice paddies as seen in the right photo below from Thailand?

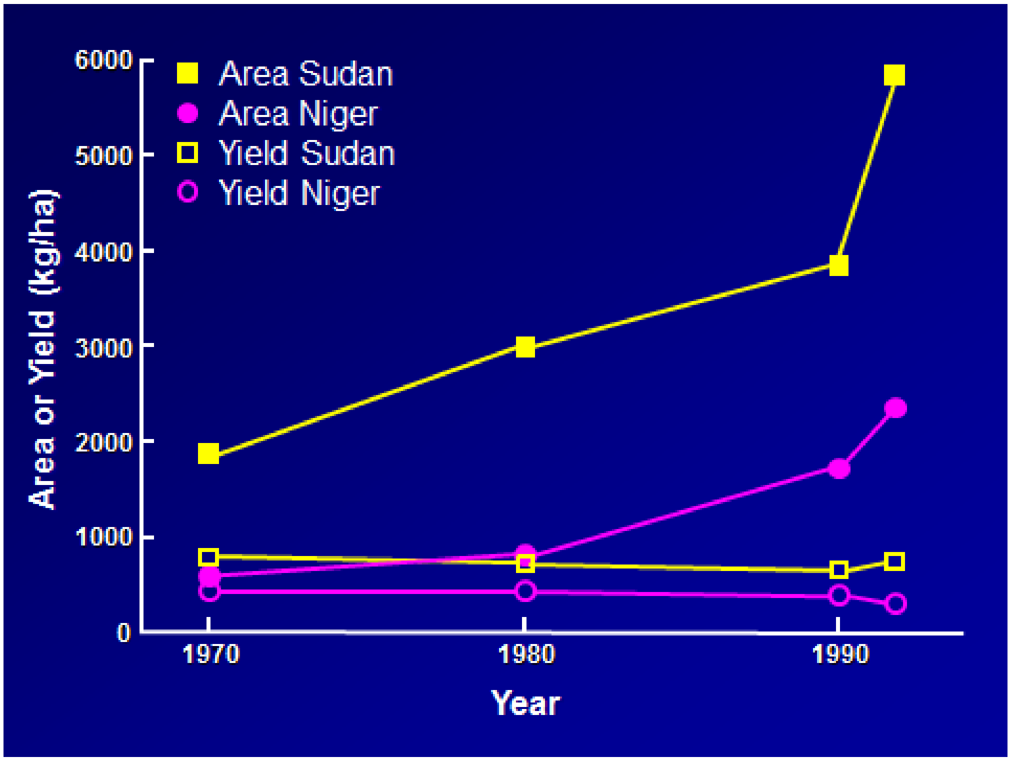


The following graph of U.S. population, total harvested acreage, acreage harvested for U.S. consumption, and fertilizer use, constructed from U.S. census reports and plotted by decades from 1910 to 1919 provides an overview of what has happened as technology has been utilized on cropland in the United States.



During that period of time the U.S. has always exported food except in 1940 when shipping to Europe was essentially halted by Nazi U-boats. Prior to 1940 acreage required for U.S. consumption closely paneled U.S. population. That drastically changed by 1950 as farming operations were mechanized following the end of World War II, genetically superior cultivars became available, and fertilizer usage greatly increased. That trend continued through 1990 with approximately one third of our harvest exported. When speaking about soils and agriculture I have been challenged by audiences critical of fertilizer and big farm machines. In response I like to show this graph and raise the following questions: What would happen if the amount of land required for U.S. consumption continued to follow the trend seen from 1910 to 1940 and extrapolate that line to 1990 when something over 400 million acres would be needed just to feed the U.S.? Without exporting food how would our trade balance be affected? Or, to be especially nasty how many National Parks would we need to plow up to grow our food?

Dennis Greenland sent me a copy of a speech he made when accepting the Russell award wherein he had assembled data that demonstrated what has taken place in countries where increased yield has not kept pace with population growth.



From Dr. Dennis Greenland

In the above figure we see how the land area used for human food has increased as yields have decreased in but two countries. No soil can continuously supply those elements that are derived from minerals in the soil, especially phosphorus needed to grow human food.

Example Total Elemental Nutrient Content in Soils

Soil	Place	Depth cm	P (kg/ha 18cm)	K (kg/ha 18cm)
Paleustalf	Nigeria	0-18	700	1700
		42-60	320	1800
Ustipsamment	Nigeria	0-18	200	700
		42-60	120	500
Haplustox	Brazil	0-18	246	ND
		42-60	212	ND
Hapludoll	Wisconsin	0-18	1,936	38,180
		42-60	1,672	37,018

Many years ago soil scientists stopped analyzing total elemental content in soils. The above table contains examples of total P and K contents in 18 cm layers of subsoil and top soil. Even if genetically improved cultivars were to become available that could produce more dense root systems or if symbiotic microbial organisms could be adapted to human food crops so that total amounts of P could be accessed the complete supply in the soil would be depleted in a finite number of harvests.

MORROW PLOT CORN YIELDS: Corn yields (Bu/Ac) After Odell et al. 1982

YEAR	NO FERTILIZER (Bu/Ac)	HIGH INPUT (Bu/Ac)
1888	54.3	ND*
1889	43.2	ND
1890	48.7	ND
1891	28.6	ND
1892	33.1	ND
1893	21.7	ND
1894	34.8	ND
1895	42.2	ND
1896	62.3	ND
1897	40.1	ND
1888-1897 AVE	40.9	ND

*ND=Not Done

MORROW PLOT CORN YIELDS: Corn yields (Bu/Ac) After Odell et al. 1982

YEAR	NO FERTILIZER (Bu/Ac)	HIGH INPUT (Bu/Ac)
1972	57.9	159.9
1973	44.0	148.6
1974	39.4	105.2
1975	48.8	161.3
1976	49.6	135.5
1977	51.1	113.0
1978	58.3	176.8
1979	35.2	115.9
1980	46.3	31.1
1981	47.0	172.3
1972-1981 AVE	47.7	131.9

In the tables above corn yields from two decades, 1888-1897 and 1972-1981 from the Morrow plots on Flanagan (Aquic Argiudolls) soils on the University of Illinois campus are presented. Corn was grown each year and as seen in the data average decade yield increased only 6.8 Bu/Ac in the non-fertilized plots even with improved hybrids that became available over that time span. After1955 subplots of the non-fertilized plots were each year fertilized (high input) according to soil test recommendations. Although continuous low level production was obtained in the non-fertilized plot on the Flanagan soil, one of the most naturally fertile soils known yields were approximately one third of what is possible with modern management.

Most soils are capable of doing many things. We can hope that modern technology can be managed to produce high yields and improve the nutrition of the ever expanding human populations. By so doing many areas of natural vegetation can be spared cultivation practices that produce meager amounts of human food.

In conclusion, it has been fun to classify what a soil is. That is the foundation for knowing what a soil can do. However, what a soil does depends almost entirely upon the economic, political, and social environment that surrounds it.